Activities of Plankton in the Natural Purification of Polluted Water*

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AS a rule, plankton and related organisms are most abundant in water which is in process of recovery from pollution by sewage, that is, during the period of natural purification. Hence we may inquire, (1) Are the activities of these organisms a part of the program of natural purification? (2) What effects, if any, are produced on the water by the presence and activities of these minute forms of life? and (3) What are some of the activities?

Biologically speaking, these microscopic organisms are low in the scale of life, have little differentiation, and relatively few activities, these being concerned chiefly with obtaining food and reproduction of species. From the standpoint of effect upon the water, the matter of food supply would seem to be dominant, and this may be discussed with advantage under the subheads—(1) plankton food, (2) photosynthesis, and (3) expenditure of plankton energy.

Some years ago a noted German investigator, Dr. Marsson, classified all plankton organisms as "food producers" and "food consumers," including in the latter class those organisms which by means of lash, cilia, or other appendage directed a current into their mouth-vacuole or gullet, thereby obtaining minute particles of food, including bacteria. Many other workers both here and abroad have observed and recorded the consistent tendency of certain plankton forms, conveniently designated "pollution organisms," to become numerous when sewage is present and bacterial content is high, and the subsequent decrease or disappearance of these same organisms when bacterial content becomes low. There is abundant presumptive evidence of this sort to the effect that certain plankton organisms necessarily find much of their food in bacteria, not only because of the simultaneous fluctuations of the numbers of the two classes of organisms, but also because of the observed methods of feeding, and the body structure of the plankton organisms as indicated by Dr. Marsson, above quoted. In fact, it would be diffi-

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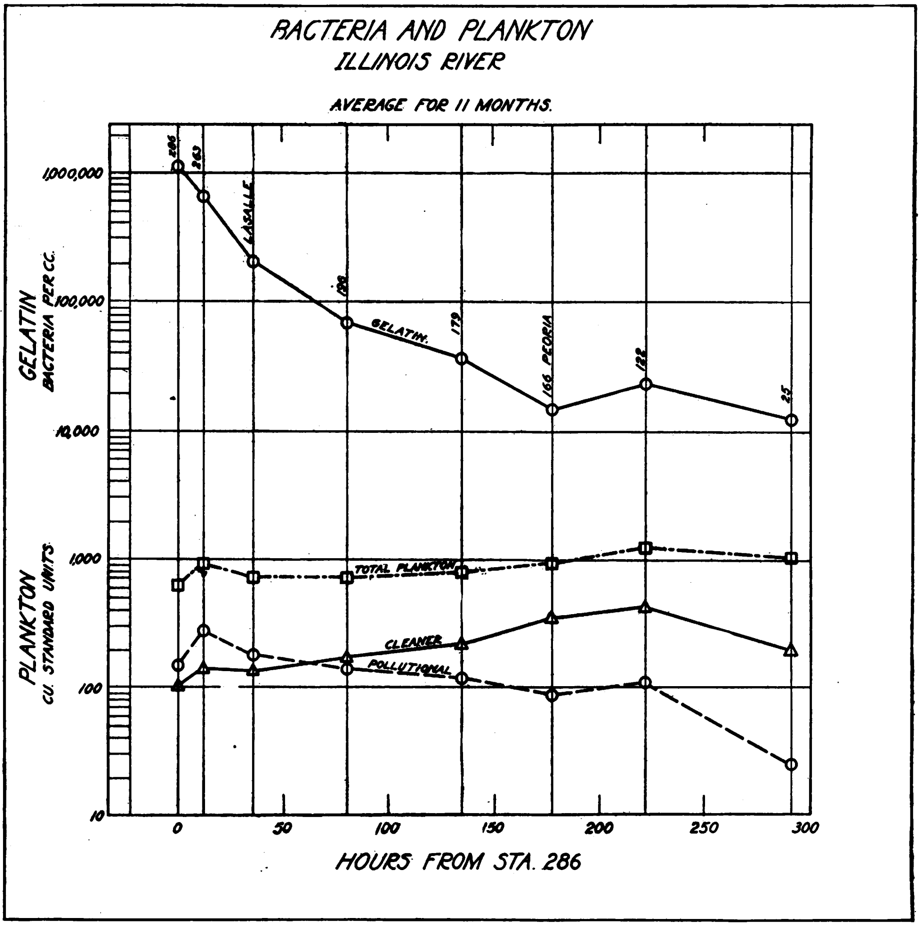
CHART I



cult, or impossible perhaps, for the feeding plankton organism to avoid ingesting large numbers of bacteria.

In three rivers thus far studied (Potomac, Ohio and Illinois), these pollutional organisms are most numerous in that part of the stream where pollution is physically evident, and decrease rapidly as the water regains normal condition. Chart I, showing decreasing bacterial content, and decreasing pollutional plankton meantime, is based on Illinois River data, and is, in general, representative of the other streams.

There is, however, quite satisfactory evidence, based on careful laboratory tests, that certain of these pollution organisms are able to consume very large numbers of bacteria, the plankton meantime increasing greatly in numbers. A brief report of these tests was published in 1918.[1] From that report we present herewith Chart IV, and one or two unpublished ones relative to the same tests.

CHART II

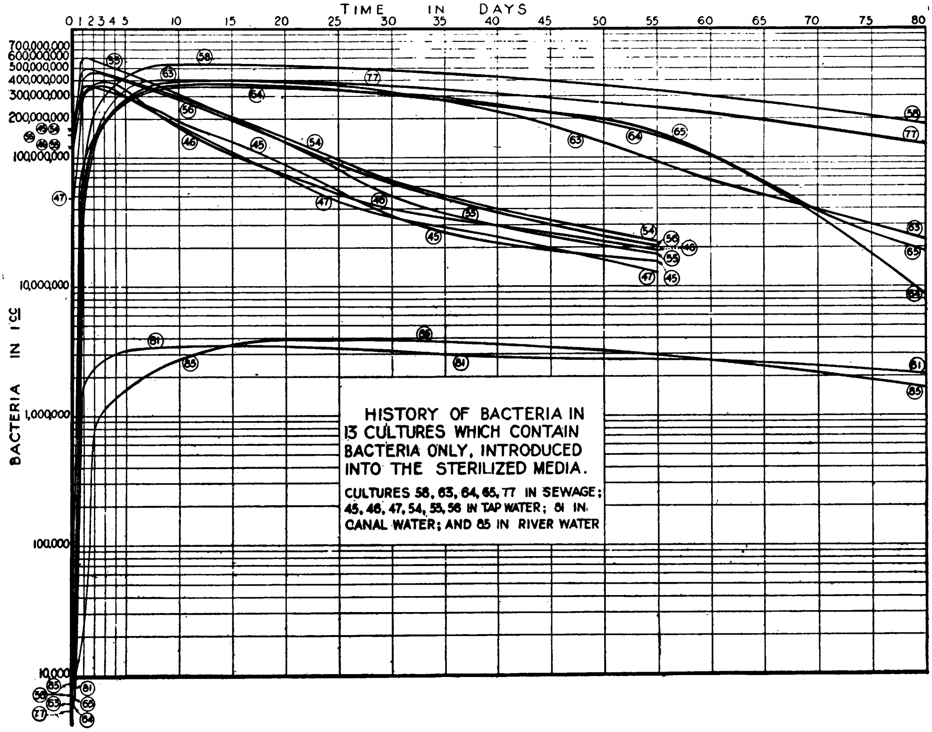
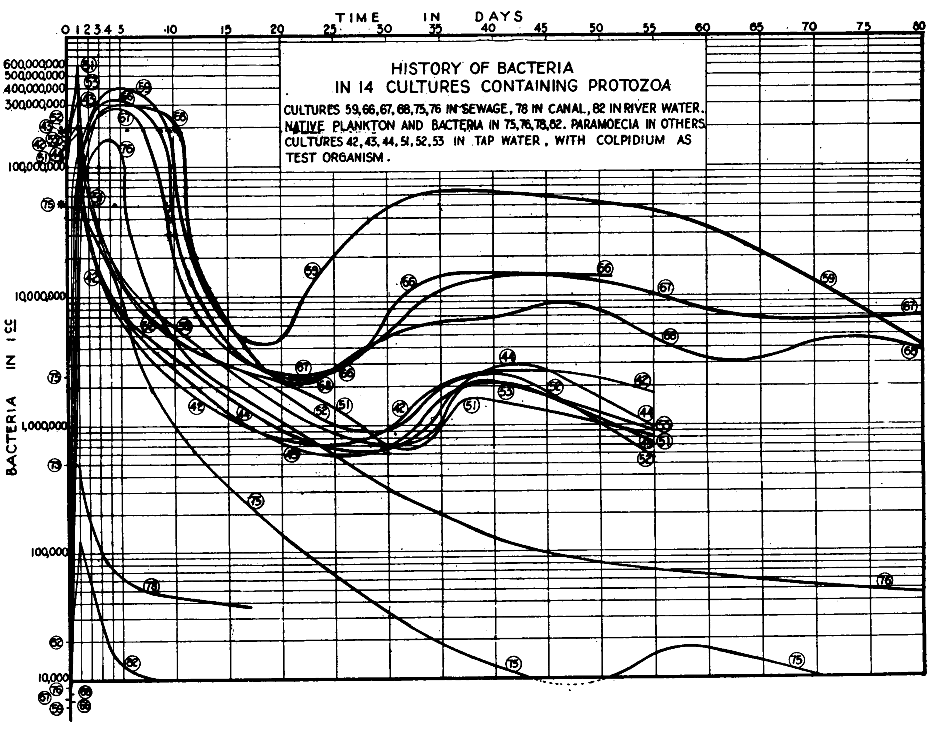


CHART III



Essential results of these tests were as follows,

1. Sterilized sewage, inoculated with bacteria only, reached a very high count in 4 to 6 days and maintained this for 6 to 10 weeks.

2. Sterilized sewage, inoculated with bacteria and also with pollutional protozoa, showed high bacterial maximum in 4 to 6 days, then shortly heavy and rapid reduction, with rapid increase in protozoa about the time of greatest bacterial decrease.

These experiments, repeated many times, always gave essentially the same results, as shown by Charts II and III.

All of the cultures shown in Chart II were of sterilized medium inoculated with bacteria only.

All of the cultures in Chart III were identical with those in Chart II, except for the presence of protozoa in the cultures. It will be noted that the bacterial history is very different. Comparison can best be made by inspection of Chart IV, here shown.

Culture 65 contains bacteria only. The very high content is maintained for about 60 days. Culture 68 is identical except that it contains protozoa, in addition to bacteria. It will be seen that, in this culture, the high bacterial content drops suddenly. It seems significant that the protozoa increase rapidly meantime.

One culture of sterilized sewage was inoculated with bacteria-free protozoa (paramecia). Apparently the minute organic detritus present, and the dissolved materials, did not constitute suitable food, for all the paramecia died within 4 days. After 14 days this same medium, still bacteria-free, was again inoculated with paramecia, but bacteria were added this time. The paramecia multiplied more than a hundredfold under these conditions.

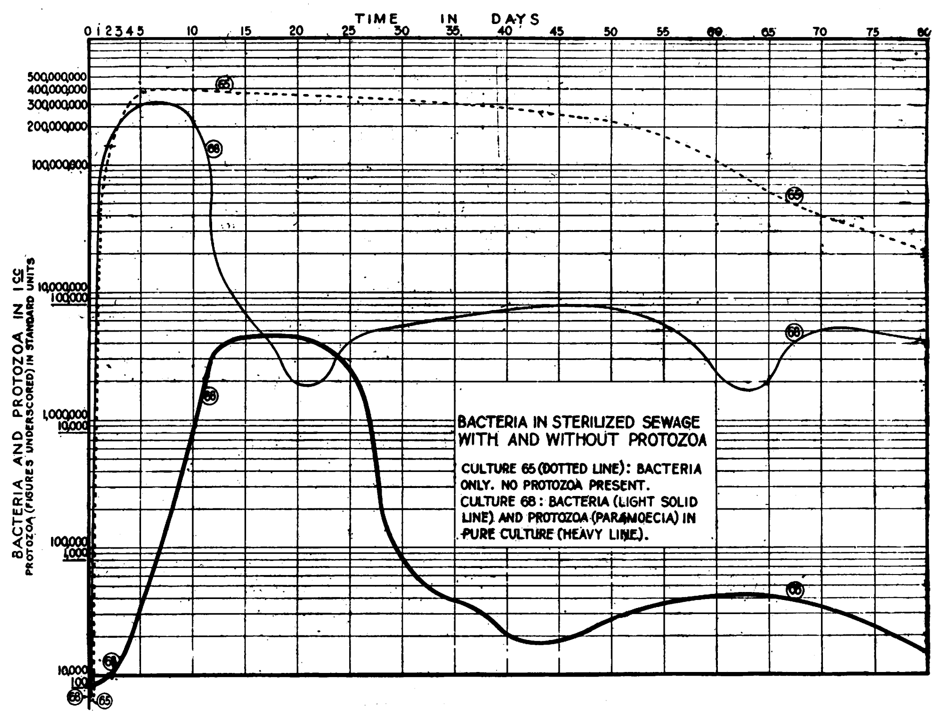
In view of all these results, as stated, it seems difficult to offer any satisfactory explanation other than that the paramecium, a typical pollution organism, consumed bacteria in large numbers. Apparent confirmation of this food habit is indicated by the speedy death of paramecia in the culture which contained no bacteria, and subsequently by the immediate increase of other paramecia in this identical flask of sterile sewage when bacteria were added.

Further laboratory tests indicate that colpidium, another typical pollution organism, is capable of living in a liquid medium (ordinary broth) without bacteria, but it failed to live in sterile sewage without bacteria added. Moreover, it will live in sterile water to which has been added a suspension of bacteria only. These facts indicate the probability that colpidium is in nature a consumer of bacteria, but that life is possible for it with a diet of dissolved organic matter alone, such as

REFERENCE

1. Purdy, W. C. and Butterfield, C. T. The Effect of Plankton upon Bacterial Death Rates, *A. J. P. H.*, VIII, 7:499 (July), 1918.

CHART IV



broth, provided this be of suitable strength. It has been suggested (by Mr. Butterfield, I believe) that the bacteria are merely the convenient agents to gather or harvest from the water and store within their bodies the highly-diluted soluble organic matter which, in the more concentrated form represented by the resulting bacterial bodies, is suitable food for colpidia and for other protozoa as well.

PHOTOSYNTHESIS

A second major activity of plankton relative to food habits should be mentioned. Reference is made to photosynthesis, by which the chlorophyll-bearing organisms of the plankton, mostly plants, dissociate carbon dioxide and water in the presence of sunlight, and in recombining the elements to form starch, the basis of their nutrition, the excess oxygen is given off as a waste product. Unless the water is already saturated, this oxygen will be dissolved to some extent and may be utilized, if needed, in the aerobic decomposition of organic matter.

Beyond the brief statement of this activity, we have as yet no experimental data to offer. We may state, however, that even in such a polluted stream as the Illinois River the major part of the plankton, volume for volume, is of the chlorophyll-bearing, oxygen-producing sort, and we venture the opinion that adequate study of this unique activity of the plankton may result in a high rating as to its significance in the program of natural purification.

EXPENDITURE OF ENERGY

1. *Locomotion*—Under the microscope, the plankton activity that is most apparent is that of physical movement. Ciliates scurry to and fro apparently at breakneck speed. Flagellates glide slowly, pulled by their one or two rotating flagella extending a body-length ahead. Oxytricha and its kind move forward, suddenly go in reverse for half a body-length, change direction and again go forward, and so on indefinitely, pursuing a most erratic course. Rotifers start their "wheels" and are thereby pulled through the water as an airplane is pulled by its propeller. Nematodes produce a series of minute maelstroms by their violent contortions, and cyclops, speediest swimmer of the plankton, together with certain other crustacea, travel by a series of leaps or jumps that have given them their popular name of "water fleas."

While the apparent speed of these minute forms is great, the actual speed is very low. A colpidium will cover nearly 1 millimeter per second, a paramecium 3 millimeters, a rotifer 2. But consideration of the *relative* speed shows that the colpidium, 50 microns long, is traveling about 20 times its own length in 1 second, the paramecium 12 times its length, the rotifer 5 or 6 times. A cyclops, hurling its sturdy body through the water 70 or 80 millimeters per second and covering about 100 times its own length meantime, holds the palm. Such relative speeds are impossible for our best motor boats.

But water, being mobile and noncompressible, is locally disturbed and displaced by the movement of a submerged body. In the case of the plankton, the submerged body is self-propelled by its lashing the water with numerous minute cilia, like microscopic oars, or by the rotary movement of flagella, simulating propellers, or by the powerful strokes of paired lateral swimming organs. The disturbance of water thus produced extends far beyond the limits of the body causing the disturbance, as the oars and propeller of a boat produce currents and eddies a boat's length or more away. A paramecium will thus cause minute but violent agitation of the surrounding water to a distance of 100 microns or more on all sides. If 50 paramecia are present in 1 cubic centimeter of water, these will, in about two minutes, subject every particle of this water to this minute and intimate mixing. In like manner, 100 colpidia will, in 22 minutes, minutely mix every portion of 1 cubic centimeter of water. Polluted water usually contains various other motile forms also, some nearly or quite as large as paramecium, others exceedingly minute, but very numerous and usually very active.

2. *Movement of attached organisms*—There are also other organisms, not free-swimming, but attached to any convenient anchorage, at the water's surface, on the bottom, at the margins, or even on small masses of suspended matter. Such organisms, usually in groups or colonies, are mainly of the vorticella type. On the open end of their bell-shaped bodies are rows of cilia in practically constant motion, bringing to each organism a minute but continuous current of water. These colonial forms are amazingly abundant in a sewage polluted stream, forming a whitish feathery coating on bottom stones or trailing from any available submerged attachment. One cubic centimeter of this whitish growth may contain over 200,000 of these minute bell-shaped organisms, and every one of these is engaged in producing the continuous microscopic water current referred to.

The sum total of the minute mixing which these various plankton organisms impose upon the polluted water must be sufficiently great to merit consideration. It is frequently the case that there are present more than 50 paramecia and 100 colpidia per cubic centimeter. But if only these be present, their movements will cause minute, intimate mixing of 1 cubic centimeter of water in one and three-fourths minutes. This being the case, it is surely a conservative estimate to credit the total population of microscopic protozoa of polluted water with complete and intimate mixture of 1 cubic centimeter of water in 1 minute. The process might be conveniently and adequately indicated by the aphorism, "Minute mixing each minute."

Effects—What is the probable effect of such minute continuous mixing and microscopic circulation thus imposed on polluted water during the period of its greatest pollution? We can only say, in the absence of experimental data, which so far as we are aware have not yet been obtained or even attempted by any one, that human experience from time immemorial and in many lines attests the great value—the absolute necessity—of thorough and intimate mixing of ingredients if proper results are to be obtained within reasonable time. In more recent years, the activated sludge process has furnished a striking example of this. It therefore seems reasonable to suppose that this microscopic circulation and minute mixing caused by plankton movements during the critical initial stages of natural purification of polluted water may be a factor of importance in the successful and speedy progress of such purification. In our laboratory, cultures of sewage, containing bacteria only, retained their foul odor and their milky turbidity for 8 weeks or more, while like cultures, which however contained actively motile plankton organisms in addition to bacteria, lost their turbidity and their foul odor in about 10 days. It is possible that the continuous movements of the plankton organisms were a factor in the latter case. More specifically, we may indicate one result which appears to come from this plankton activity.

These organisms find their food in the polluted water, for they live and multiply therein. As the water slowly regains normal condition apparently this food slowly disappears also, for the organisms lose their plumpness, become thin, then gradually disappear. Apparently the organic matter that constitutes the *pollution* of the water constitutes also, to a great extent, the direct or indirect food of certain plankton organisms that are then numerous. Thus a portion of this polluting organic matter of the water reappears as a multitude of minute living organisms whose rapid and continuous movements represent the *energy* of the organic food they have consumed. In other words, a portion of the harmful organic matter is consumed, then released to the water in terms of motion. Latent energy in harmful organic form has now become kinetic and harmless, and is made to do work concerned with the betterment of the water itself. Correlation of energy is effected, and the polluted water is started on the road to recovery.

3. *Movement of larger organisms*—Certain larger organisms attack masses of organic matter or work in the bottom sediments. *Cypris,* a plankton crustacean, works the surface of sediment over and over until this is reduced to a state of microscopic fineness. The naiid worm *Dero,* occasionally found in the plankton, is frequently very abundant in heavy surface films, where it attacks and burrows into masses of organic matter, apparently eating almost continuously, judging from the great frequency and relatively large amount of its fecal excretions meantime. *Limnodrilus,* an oligochaete worm which does not belong to the plankton proper, delves in rank bottom sediments and works these over, excavating beneath the mud surface and depositing this material on the sediment surface in the form of great numbers of fecal pellets dropped from the anal end waving to and fro meantime in the overlying water. Certain other organisms also help to reduce these larger masses of organic matter or of sediment, but the three just mentioned are outstanding in their activity.

SUMMARY

It is our opinion that the activities of plankton and related organisms constitute a part of the program of natural purification of polluted water, in that their food habits tend to remove a portion of the organic matter, the photosynthetic activities of chlorophyll-bearing organisms operate to produce oxygen, and the energy of harmful organic matter consumed as food and released to the water in terms of motion, serves to furnish an intimate mixing and microscopic circulation during the critical initial stages of recovery from pollution.